Two-photon exclusive production of supersymmetric pairs at the LHC

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Abstract. The two-photon exclusive production of charged supersymmetric pairs at the LHC has a clean and unique signature - two very forward scattered protons and two opposite charged leptons produced centraly. For low-mass SUSY scenarios, significant cross-sections are expected and background processes are well controlled. Measurement of the forward proton energies would allow for mass reconstruction of right-handed sleptons and the LSP with a few GeV resolution. Methods to reduce backgrounds at high luminosity resulting from accidental coincidences between events in the central and forward detectors are discussed.

Keywords: Photon interactions, Forward scattering, Exclusive production, Kinematic constraints and reconstruction, Time-of-flight detectors

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1. HIGH-ENERGY PHOTON INTERACTIONS AT THE LHC

The $\gamma\gamma$ and γp interactions at the LHC offer interesting potential for the studies of the Higgs boson, quartic gauge couplings and the top quark as well as for searches of New Physics [1]. In particular, the clean and striking experimental signatures of the exclusive processes $pp \to pXp$ (forward regions devoid of any hadronic activity apart from presence of two forward scattered protons) are well suited for the search of new charged massive particles beyond the Standard Model [2, 3].

2. DETECTION OF EXCLUSIVE SUSY PAIRS

The two-photon pair production mechanism is simple and often results in simple final states (as shown in Figure 1), in contrast to many other cases at the LHC with usual complex decay chain problems. In fact, the exclusive pair production cross-section

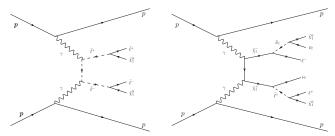


FIGURE 1. Most relevant Feynman diagrams for $\gamma\gamma$ production of slepton pairs (left) and chargino pairs (right), both with two charged leptons in the final state.

TABLE 1. Cross-sections of exclusive signal processes for production (σ) , after applying central and forward detectors acceptance cuts $(\sigma_{acc}^{2p^+})$ and after applying analysis cuts (σ_{ana}) .

Processes	σ [fb]	$\sigma_{acc}^{2p^+}$ [fb]	σ_{ana} [fb]*
$\gamma\gamma ightarrow ilde{\ell}_R^+ ilde{\ell}_R^-$	0.798	0.445	0.357
$\gamma\gamma ightarrow ilde{\ell}_L^+ ilde{\ell}_L^-$	0.183	0.093	0.073
$\gamma\gamma ightarrow ilde{ au}_i^+ ilde{ au}_i^-$	0.604	0.001	0.001
$\gamma\gamma ightarrow ilde{ ilde{\chi}}_i^+ ilde{ ilde{\chi}}_i^-$	0.642	0.021	0.015
$\gamma\gamma \rightarrow W^+W^-$	108.5	1.463	0.168

^{* &#}x27;ana' means $W_{miss} > 194$ GeV, $W_{\gamma\gamma} > 236$ GeV, $\Delta(\eta) < 2.1$, $\Delta(R) < 3.2$, $P_T^{miss} > 5$ GeV, $W_{lep} \notin [87 \text{ GeV}; 95 \text{ GeV}]$

is given by the SUSY particle mass and its charge and spin [1]. Only the final states containing exactly two charged leptons have been assumed in this study as well as the low mass point LM1 [4] as a benchmark¹.

Assuming a general multi-pupose LHC detector and a full-set of dedicated very forward detectors (VFDs) to tag γ -interaction [5, 6], the event selection requires:

• two isolated leptons of opposite charge detected in the central region assuming

$$p_T(\mu^{\pm}) > 7 \text{ GeV}, \quad p_T(e^{\pm}) > 10 \text{ GeV}, \quad |\eta(\ell^{\pm})| < 2.5$$
 (1)

• two scattered protons detected in the VFDs assuming the tagged photon energy range [7]

$$20 < E_{\gamma} < 900 \text{ GeV} \tag{2}$$

- large missing energy due to the escape of neutrinos and neutralinos²,
- lepton acoplanarity.

The only irreducible background process for such an event topology is the exclusive $\gamma\gamma$ production of W pairs with fully leptonic decay. The cross-sections after acceptance cuts (including same flavour requirement and rejection of τ -lepton tagged events) are 0.56 fb and 1.46 fb for the signal and background respectively, as detailed in Table 1.

3. PRECISE MASS RECONSTRUCTION

The detection of the two scattered forward protons and the associated measurement of the photon energies allow for precise reconstruction of the two-photon 'initial conditions'. The distributions of the two-photon invariant mass $W_{\gamma\gamma} = 2\sqrt{E_{\gamma_1}E_{\gamma_2}}$ and of the missing mass W_{miss} (reconstructed from $E_{miss} = E_{\gamma_1} + E_{\gamma_2} - E_{\ell_1} - E_{\ell_2}$) are shown on

¹ All the details about the considered SUSY parameters and mass spectrum can be found in [3].

 $^{^{2}}$ $\tilde{\chi}_{1}^{0}$ is taken as the Lightest SUSY Particle (LSP) in this model.

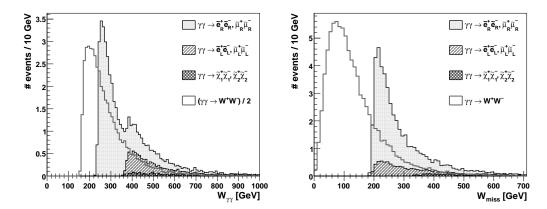


FIGURE 2. Distributions of the two-photon invariant mass $W_{\gamma\gamma}$ (left) and the missing mass W_{miss} (right) for the integrated luminosity $L = 100 \text{ fb}^{-1}$. The background distribution of WW pairs is shown separately. All the distributions are obtained for events passing the acceptance cuts (1) and (2) only, with 2 leptons of opposite charge but same flavor.

Figure 2. The $W_{\gamma\gamma}$ distribution reflects the SUSY mass spectrum with two peaks due to the production thresholds of $\tilde{\ell}_R$ pairs (\simeq 250 GeV) and $\tilde{\ell}_L$ pairs (\simeq 400 GeV). Similary the W_{miss} distribution starts around twice the mass of the LSP for the signal, and around zero for the background. These distributions can be used to perform a mass edge study and extract the masses of $\tilde{\ell}_R^+$, $\tilde{\ell}_L^+$ and $\tilde{\chi}_1^0$. Furthermore, combination of both information allows to measure the mass of light $\tilde{\mu}_R$ and \tilde{e}_R using empirical quantity [3]:

$$(2 \times m_{reco})^2 = W_{\gamma\gamma}^2 - \left(\left[W_{miss}^2 - 4m_{\tilde{\chi}_1^0}^2 \right]^{1/2} + \left[W_{lep}^2 - 4m_{lep}^2 \right]^{1/2} \right)^2 \tag{3}$$

The only input is this method is the LSP mass, which can be taken from the W_{miss} edge study. The m_{reco} distribution is shown in Figure 3 after applying the analysis cuts (see Table 1) for the integrated luminosity of 100 fb^{-1} . A narrow peak centered on $2 \times m_{reco} = 100 \text{ fb}^{-1}$

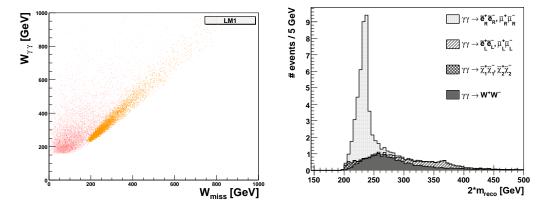


FIGURE 3. Left: Scatter plots for the $\tilde{\mu}_R^+ \tilde{\mu}_R^-$ signal (light) and WW background (dark) in the W_{miss} , $W_{\gamma\gamma}$ plane. Right: Cumulative distribution of the reconstructed mass $2 \times m_{reco}$ (3) for the integrated luminosity $L = 100 \text{ fb}^{-1}$ assuming no pile-up conditions, after the analysis cuts.

236 GeV = 2×118 GeV demonstrates possibility of an event-by-event determination of the \tilde{e}_R^{\pm} and $\tilde{\mu}_R^{\pm}$ mass with few GeV resolution.

4. ACCIDENTAL COINCIDENCE BACKGROUND

To be sensitive to the fb-level cross-sections, such studies have to be performed at the nominal LHC luminosity. The large event rates lead then to large backgrounds due to accidental coincidences of dileptonic events in the central detector and two forward protons detected in the VFDs, but not coming from the same vertex [6, 8]. The effect of multiple interactions per beam collision was simulated by superimposing over dileptonic inclusive events³ $\langle N \rangle$ overlap events on average⁴, and by distributing the extra vertices according to a 48.2mm wide Gaussian [9]. The probability to detect two diffractive accidental protons per beam collision (one on each side of the interaction point) is expected to be on average 1.2% at low and 21.5% at high luminosity. The associated background cross-sections reach 2.4×10^4 fb and 4.5×10^5 fb respectively.

This background can be reduced using the tracks associated to the dilepton vertex, which are not present in the exclusive events. One can therefore request no extra track with $p_T > 0.5$ GeV (where 100% reconstruction efficiency is assumed) associated to the $\ell^+\ell^-$ vertex. It provides a background reduction of 4500. Further background reduction can be made using precise time-of-flight proton detectors with a few picosecond resolution, and by reconstruction of the event vertex position from the proton timing [6, 10].

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 $^{^3}$ We considered inclusive $Z/\gamma*$, ZZ and WW production. 4 $\langle N \rangle = 5.08$ for $\mathscr{L} = 2 \times 10^{33} cm^{-2} s^{-1}$ and $\langle N \rangle = 25.38$ for $\mathscr{L} = 10^{34} cm^{-2} s^{-1}$